TRANSACTIONS
OF
THE OPTICAL SOCIETY.

Vol. XVIII. JANUARY and FEBRUARY, 1917. No. 1.

THE COUNCIL has decided that in future the "Transactions" will be issued in a fresh style and of different size from those hitherto published; this number is the first of such issues. The size is that of the "Proceedings of the Royal Society," and also, as near as possible, that of the new journal to be published by the Optical Society of America.

Ordinary Meeting, 11th January, 1917.

F. J. CHESHIRE, F.R.M.S., President, in the Chair.

The meeting was held at King's College, Strand, concurrently with an Exhibition of Workshop Methods of Optical Testing; an account of the latter will be given in a supplementary number of the "Transactions."

The following were balloted for, and duly elected to the Society:—

As Members.

LIONEL P. BOOTH, M.A., F.R.A.S., Farnborough.
DAVID BRADFIELD, Messrs. Watson and Sons, High Barnet.
THOMAS CHARLES, Messrs. Carl Zeiss (London), Ltd., London.
MICHAEL B. FIELD, M.Inst.C.E., Messrs. Kelvin, Bottomley and Baird, Ltd., Glasgow.
PATRICK A. GIBNEY, Messrs. Sir Howard Grubb and Sons, Ltd., Dublin.
CHARLES L. REDDING, Northampton Polytechnic Institute, London
JULIUS RHEINBERG, London.
F. PARKER WOOD, Messrs. Baroux and Bion, Ltd., London.
R. S. WRIGHT, Messrs. Newton and Wright, London.

ANNUAL GENERAL MEETING.

The undermentioned candidates were proposed for election as Members, the name of the proposer from personal knowledge being appended :—

William Anderson, Putney (William Shackleton).
J. E. Barnard, London (F. J. Cheshire).
George A. Carse, M.A., D.Sc., Woolwich (A. C. Williams).
Charles Cochrane, M.A., B.Sc., London (W. Shackleton).
A. V. de Braun, London (S. D. Chalmers).
G. A. Richmond, London (J. W. Hasselkus).
Allan R. Robson, London (S. D. Chalmers).
Victor Towns, London (F. Watts).

After being moved from the Chair, it was resolved by acclamation "That the best thanks of the Optical Society be accorded to the Delegacy of King's College for their kindness in granting facilities for the holding of the Society's Exhibition of Workshop Methods of Optical Testing at the College on the 11th January, 1917."

Annual General Meeting, 8th February, 1917.

The Annual Meeting of the Society was held on 8th February, at the Rooms of the Chemical Society, Burlington House, W., Mr. F. J. Cheshire, F.R.M.S. (President), in the Chair.

The Hon. Secretary (Mr. W. Shackleton) read the minutes of the last annual meeting, which were duly confirmed.

The President formally moved the adoption of the annual report of the Council, and of the accounts for the year 1916.

Dr. Rosenhain, in seconding the motion, said the report was eminently satisfactory. To himself, as a somewhat ancient Past President of the Optical Society, it was particularly gratifying to see how well the Society had prospered and grown in recent years, and he was sure all the older members must feel that the Society owed a debt of gratitude to the previous and present Presidents, the officers, and the Council for the way in which they had worked up the Society into a really representative body standing for the whole optical industry of this country.

Mr. H. F. Purser (Hon. Treasurer) thought it might be useful if he made one or two remarks in reference to the financial position of the Society. As Dr. Rosenhain had pointed out, there had been quite considerable signs of growth in the Society of late, especially during the last two years. That progress was due in the first place to the initiation of a new policy by the late President, Dr. Ettles, who, during the last year of his occupancy of the presidential chair, had formulated the idea that it would be advisable to entice into the Society the scientific instrument manufacturing portion of the industry, and also, in greater numbers, those connected with the academic side. That policy had apparently been successful, and to that extent they owed a debt of gratitude to the late President. But he was sure they had all recognised that in their present President they had the one man who could, and who undoubtedly had, helped forward the development of the Society to the greatest possible extent. It was his driving force which had brought the Society to the state in which it was to-day.

In 1915 the Society's expenditure was £163, in 1916 it was £191; yet, notwithstanding that increased expenditure, the accounts showed a balance* in the bank of £52 5s. 1d. This was all the more satisfactory because, looking back upon some of the records of the past, he found that year after year they had had to report deficits of £20, £30, and £40.

On a former occasion he had pleaded with the members of the Society to help the Council and the Secretary, as well as the Treasurer, by answering correspondence and by paying promptly their subscriptions. He was happy to say that this year the unpaid subscriptions numbered only 26½, whereas in 1915, with a smaller membership, they amounted to 39½. He wished to take that opportunity of thanking members for the way in which they had responded to that appeal, and he hoped they would continue in well-doing.

Northampton Institute Fund.

There was an item in the balance sheet of £10 14s. 4d. standing to the credit of the Northampton Institute Fund, and at the Council meeting that afternoon it had been decided to hand over that sum to the Institute. No doubt Dr. Walmsley would have a word or two to say on that matter, and it was only necessary for him to remind them that the Northampton Institute Fund was instituted by the late Mr. James Aitchison at a time when the Northampton Institute was requiring assistance in order to keep going the optical classes that were then being held. It was one of the tragedies of the optical industry, and perhaps also of education generally, that so little effort had been made by the governing authorities to provide technical education; for, with the failure of the apprenticeship system, it undoubtedly became very essential and necessary that technical education should be more freely and extensively provided. Even to-day there was evidence of the miserly manner in which the governing authorities treated this question. Take, for instance, the London County Council, which at the present time was proposing to give one shilling per week increase on the salaries of the teachers. There had been exhibited in almost every grade of education this absence of recognition of the necessities of education, and if the British optical industry was to hold its proper place in the world a tremendous amount of leeway would have to be made up in that direction, and it would become necessary for the Optical Society, and also for the optical industry as a whole, to support to the utmost possible extent the efforts that would have to be made to secure a greater increase in technical education. It was tragic to look back and imagine what might have been done had the Northampton Institute, in early days, been supported by the London County Council and the education authorities generally, and to consider the different position which the optical industry might have held to-day had action been taken at the right and proper time.

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* Of the reserve funds of the Society, £200 has now been invested in the War Loan.

The Aitchison Scholarship.

In connection with this subject there was another scheme which was still in being, though the war had rather put it in the background, and he recalled it at that moment because of its association with the late Mr. James Aitchison. He referred to the Aitchison Memorial Fund. Although that fund, strictly speaking, did not come under the control of the Optical Society, he was sure he would be pardoned for mentioning it, because of its connection with education. Some of them would remember that the fund in question was instituted in memory of the late Mr. James Aitchison in order to assist, by means of a scholarship, technical education in optics. A sum (of about £200) had been gathered together, and although as a result of the war the matter had had to be put aside for the time being, it was hoped that a great number of subscribers would come forward before the end of the war, so that it might be possible, immediately after the conclusion of peace, to place this scholarship on a satisfactory footing. At the present time, owing to the paucity of youths applying for education of any kind, it had not been possible to give the scholarship in question, but he ventured to plead with the members of the Optical Society, not only out of respect to the memory of Mr. James Aitchison but also because of the utility of the fund, to give their generous assistance in establishing it so that when the war was finished it would stand upon a firm basis and be enabled to do its proper work in encouraging the optical industry.

Dr. R. Mullineux Walmsley said that the Northampton Institute Fund, which had been administered by the Optical Society for many years, but which was now—he hoped only temporarily—being closed, had been of very great assistance to him, not so much from the financial side as by reason of the moral effect of such a fund. He was sorry to say that, notwithstanding the assistance rendered by the fund, some of his most cherished efforts to promote optical education had not borne, before the war, the fruits which, had they been borne, would, he thought, have made a considerable difference to the position of this country on the outbreak of hostilities. It was somewhat difficult to realise that since 1902 he had been asking for proper public recognition of optical education, and year after year, in those days before the war, when he was confronted, as he often was, with the question, "What is the trade doing?" he had been able to point to the Northampton Institute Fund of the Optical Society and say, "The trade is doing its best; it is not a wealthy trade, but it is doing something, and should be supported." That was an old controversy with the authorities, and he did not want to revive it at the present time; it would be impolitic for him to do so; but he hoped the few remarks he was making would not be taken by the Optical Society as a funeral service on the Northampton Institute Fund, and that that fund was only suspended. He most warmly thanked the Society for the assistance which it had rendered to the Northampton Institute in the past, and he hoped, for the reason he had given, that the fund would be revived in the future.

Advanced Instruction Suspended.

Mr. Purser had referred also to the Aitchison Memorial Fund, and although it was strictly correct to say that this was not officially connected with the Optical Society, he should always himself regard it as an Optical Society fund; it had been largely indebted to the members of the Optical Society in the past, and he hoped with Mr. Purser that it would be still more so in the future. It was not surprising that at the moment it was not possible to get a scholar to take the Aitchison scholarship, because at the present time scholars could not be got to take anything. Advanced instruction, not only in technical optics, but in technical engineering and other subjects, was for the time being suspended, except as regarded foreign students, and perhaps these need not be brought into the account.

They would be in possession within a few days of a most important Report upon Instruction in Technical Optics, in which their President had had a very great hand. The Report in question had been adopted by the Board of Scientific Societies of the Royal Society, and he was distinctly authorised to say that it was public property, and would be published very shortly. In reading that report they should, if possible, compare it with a report adopted by the London County Council at its last meeting before the August vacation. There were many points of difference, and it would ill become him, as one personally interested—in his official capacity as Principal of the Northampton Institute—in both reports, to draw attention to what those differences were. But he did commend to every member of the Optical Society who was interested in education in technical optics, that he should compare these two reports and form his own opinion upon the matters dealt with therein.

The motion for the adoption of the report and accounts was then put to the meeting, and carried unanimously.

Election of Officers.

The PRESIDENT announced that the following gentlemen had been proposed by the Council for office during the year 1917-18, and as no other nominations had been received from the Members of the Society, he declared them duly elected :—

President—F. J. CHESHIRE, F.R.M.S.
Hon. Treasurer—H. F. PURSER.
Hon. Secretary—WM. SHACKLETON, A.R.C.Sc.
Hon. Librarian—J. H. SUTCLIFFE.
Members of Council—L. C. MARTIN, B.Sc., D.I.C.
W. ROSENHAIN, D.Sc., F.R.S.
T. SMITH, B.A.
FRANK TWYMAN.
R. MULLINEUX WALMSLEY, D.Sc.
R. S. WHIPPLE, M.A.
LT.-COL. A. C. WILLIAMS.

The names of those remaining in office are as follow :—

Council.

I. AITCHISON, B.A., LL.B.
MALCOLM BENTZON.
G. B. BRYAN, D.Sc.
ARTHUR B. CLARK.
R. S. CLAY, D.Sc.
T. F. CONNOLLY, M.Sc.
F. W. DADD.
HENRY R. FAIRBANKS.
ERNEST A. GILMORE.
HENRY A. HUGHES.
JAMES LUCKING.
JAMES P. PETHERICK.
JOSEPH PIZZALA.
G. F. C. SEARLE, D.Sc., F.R.S.

LT.-COL. A. C. WILLIAMS then moved :—" That the best thanks of the members be accorded to the officers and members of Council for their services to the Society during the past year."

MR. C. L. REDDING formally seconded, and the motion was carried by acclamation.

The PRESIDENT, in acknowledging the vote of thanks, said that, speaking for himself, and, he was sure, for every other member of the Council, they thanked God every day that the war had found them young and vigorous enough to strike a blow for their country. The present was undoubtedly the only opportunity that had occurred within the last half-century for the resuscitation of the English optical industry.

The war had made it imperative in the national interests that the English optical industry should live, and if that industry must live it must be represented by an optical society. The Optical Society therefore had now got the chance of its life, and they were all delighted at the way in which that opportunity was being taken advantage of by the members of the Society. He felt quite sure that when the war had ended, and the proceedings of the Society were read quietly by the fireside, it would be admitted by everyone that the Optical Society at any rate had done its duty. That was what they were there to do ; he was glad that the Society considered that the officers and Council had done their duty, and he assured them once more that they would continue to do it.

The annual meeting then terminated. The proceedings of the ordinary meeting immediately followed.

Ordinary Meeting, 8th February, 1917.

F. J. CHESHIRE, F.R.M.S., President, in the Chair.

The following were balloted for, and duly elected to the Society :—

As Members.

WILLIAM ANDERSON, Messrs. Butters and Anderson.
J. E. BARNARD, King's College, London.
GEORGE A. CARSE, M.A., D.Sc., Royal Arsenal, Woolwich.
CHARLES COCHRANE, M.A., B.Sc., London.
ALEXANDER V. DE BRAUN, Messrs. Periscopic Prism Co., London.
G. A. RICHMOND, Messrs. Ross, Ltd., London.
ALLAN R. ROBSON, Messrs. E. R. Watts, London.
VICTOR TOWNS, Messrs. E. R. Watts, London.

The undermentioned candidates were proposed for election as Members, the name of the proposer from personal knowledge being appended :—

MAURICE BLOOD, M.A., F.C.S., F.R.M.S., London (F. J. Cheshire).
A. E. CONRADY, F.R.A.S., F.R.M.S., London (F. J. Cheshire).
E. B. KNOBEL, F.R.A.S., London (F. J. Cheshire).
J. H. LEECH, High Barnet (J. S. Wilson).
ARTHUR S. NEWMAN, London (J. A. Sinclair).
E. H. SMART, London (F. J. Cheshire).

GLASS GRINDING AND POLISHING.

Dr. R. S. Clay (in the absence of the author) read the following paper by Mr. James W. French, B.Sc., of Glasgow :—

More Notes on Glass Grinding and Polishing.[*]

By JAMES WEIR FRENCH, B.Sc.

Recently I had the honour of delivering to the Optical Society a paper entitled, "Some Notes on Glass Grinding and Polishing." Certain of the statements in that paper were made the subject of considerable discussion, a number of the members finding it difficult to accept some of my conclusions without further evidence. It was the intention to confine the present paper to certain features of the surface layer, but considering the interest taken in the subject of the first paper, I have re-written and amplified the second one.

In order to avoid unnecessary repetition of material it is advisable to re-state briefly some of the principal points that were the subject of most criticism. For purposes of description, the original glass as before will be referred to as the Alpha material and the surface layer as the Beta material.

The principal statements may be summarised as follows :—

(*a*) That it is not possible to produce on the Alpha glass scratches that resemble those exposed in etching a Beta surface ;

(*b*) That, owing to the small cohesion of the silicates as compared with metals, there is no covering over of pits such as the most minute gas bell cavities in the Alpha material, in which foreign material could lie ;

(*c*) That sleeks are scratches in the Beta material ;

(*d*) That the sleeks exposed on etching are associated solely with the Beta material ;

(*e*) That the polishing action and removal of material occur simultaneously, but in varying proportions ;

(*f*) That the thickness of the Beta layer is about eight wave lengths.

It is not the function of this paper to discuss processes of manufacture, but in order to understand the nature of the polished surface layer of glass, it is of assistance to know how it may be produced.

In one process, very commonly, though not universally adopted, there are three well-defined operations :—

1. Rough grinding or forming.
2. Smoothing.
3. Polishing.

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[*] For the loan of the blocks, the Society is indebted to "The Optician and Scientific Instrument Maker."

For the first operation a coarse abrasive, such as carborundum, emery or sand, is employed. The amount of material removed is very great, as compared with the pseudo-polish effect. The object of the operation is to shape the glass roughly by the economical removal of material.

For the second operation finer grades of carborundum or emery are used. As compared with the first operation, the amount of material removed is less and the pseudo-polish effect is greater. The object of the operation is to shape the glass by the fine removal of material, both as regards final angle and size. So fine is the surface produced in practice that the size is not generally reduced in the succeeding polishing operation by more than 1/100 mm., and the change of angle due to the actual production of the polished layer can be controlled within a very few seconds over a length of 25 millimeters.

In both first and second operations, the abrasive may be used in a loose form and applied with a lubricant such as water by means of a surface grinding tool, usually of close-grained cast-iron, or it may be in the form of a grinding wheel.

Operations (1) and (2) differ only in degree and might be regarded as one stage.

When manufacturing large quantities of the same piece supplied as moulded blocks of approximately the correct size and shape, the finest grades of abrasives may be used in the first operation and the pieces may be formed to the final dimensions both as regards size and angle. As the limits of dimensions imposed may be as small as one-thousandth of an inch, and the limit of angle one minute—that is, one three-thousandth of an inch per inch—it will be evident that modern optical work is comparable with good mechanical work as regards dimension, and that an equipment of precision tools is necessary for the so-called roughing shop. For this reason it is preferable in the case of manufacturing work to use the word " forming " in place of " roughing."

For the smoothing operation under the circumstances above mentioned the same fine grade of abrasive may be employed. The purpose of the operation is then to correct any minute irregularities over the surface of the block of prisms after the individual parts have been laid down and cemented. The purpose is not to control the size and angle.

Abrasion.

In the first instance the action of a single grain will be considered.

Suppose in Fig. 1, A is a grain of carborundum lying between the glass C and the metal tool B. The direct or percussive load on the tool is concentrated at the point of contact of the grain and the glass.

From Fig. 2, which shows several grains of carborundum, it will be seen that, as indicated in Fig. 1, the grain will generally transmit the load through the obtuse apexes of polyhedral angles.

The intensity of pressure, *p*, will depend upon the area of contact; thus the sharper the point, the greater will be the intensity.

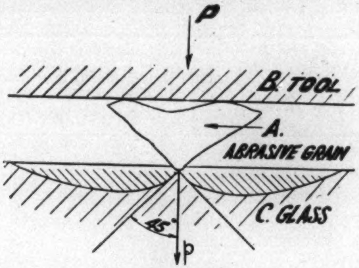


FIG. 1.

An abrasive, to be effective, should have obtuse apexes or rounded points of large curvature. Lamellar or schistose materials are not likely to be good glass abrasives.

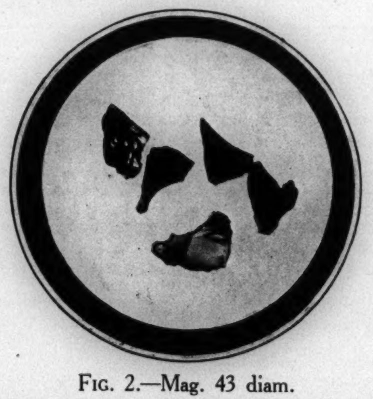


FIG. 2.—Mag. 43 diam.

To some extent the area of contact will depend upon the elastic properties of the glass and the grain. Thus the intensity of pressure will depend upon the bulk and rigidity moduli of the glass and of the abrasive, the former being generally the predominant factor. The amount by which the grain sinks into the glass is a matter of very great importance.

Glass, like most non-ductile materials, has very low tenacity, compared with its resistance to compression. Under the action of the longitudinal pressure it accordingly fractures along the planes of maximum shear, which are inclined to the axis at angles of about 45 deg.

As indicated in Fig. 1, splintering commences along the oblique planes of maximum shear. But under the wedging action of the grain the shear plane is deviated upwards and a conchoidal splinter is formed. An identical effect is often produced by the pressure of, say, a cart-wheel upon the hard, wet sand surface of the sea-shore, or even in walking, by the pressure of the toe of the boot.

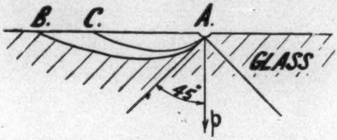


FIG. 3.

Abrasion quantitatively depends, not only upon the intensity of pressure p, but also upon the wedging or lateral force. Thus, in Fig. 3, if AB is the splinter formed under the pressure p and a lateral force q, AC will be the shallower and shorter splinter formed under the action of a smaller pressure than p, provided the lateral force q is correspondingly diminished. Under such circumstances a reduction of the intensity of pressure would result in a reduction of the material removed.

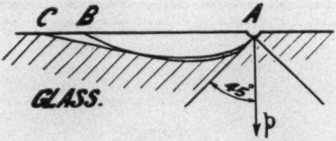


FIG. 4.

But the wedging action is dependent upon other considerations, and may not vary with the intensity of pressure p.

As indicated in Fig. 4, it is conceivable that under new conditions the reduction of pressure may be associated with a greater wedging component and that a shallower but longer splinter AC, having a greater volume, may be produced.

Some writers, when dealing with abrasives for glass, speak of the cutting edges of the grains. No doubt there is considerable truth in the statement that the grains of abrasive on the surface of metal working wheels act like the teeth of a milling cutter. This, however, is not the case when working glass, and the sharp edges clearly indicated in Fig. 2 are a feature of secondary importance.

It is quite conceivable that a grain, as in Fig. 5, may bear upon points along the edge D as well as at a point B and that if the tool is moving in the direction E, considerable forces may be transmitted through the points of D, but any removal of material will be as before due to the bursting pressure exercised by bearing points along the edge D. Glass is a substance so different from most metals that it is not safe to judge one from the action of the other.

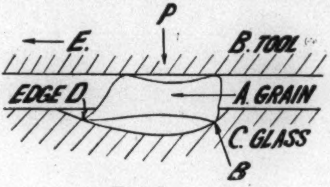


FIG. 5.

In the above discussion it has been assumed that the abrasive grain is of homogenous material whose hardness greatly exceeds that of glass. This assumption neglects what is probably the most important quality of a good abrasive, that is, its resistance to shear, which determines its durability.

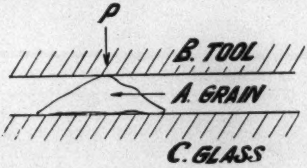


FIG. 6.

An abrasive may be extremely hard along one direction and very weak along others. This may be due to crystalline structure, to internal stress and to the existence of planes of cleavage, possibly caused by impurities.

If a grain of abrasive has a well-defined plane of cleavage, it will sometimes present, as indicated in Fig. 6, a flat surface which may distribute the total load to such an extent that the intensity of pressure is not sufficient at any point to shear the glass. In practice the grain is said to lose its cut. But, as already stated, the loss of cut is not due to the blunting of edges, as is so often stated. The grain has permanently lost its abrasive power, due to its bad change of form. It has no wearing property.

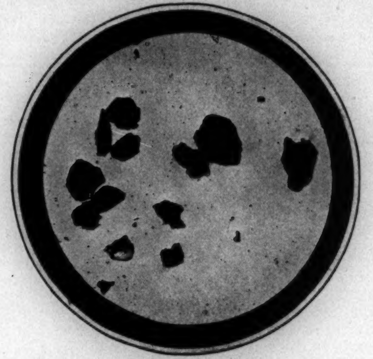


FIG. 7*a*.—Mag. 43 diam.

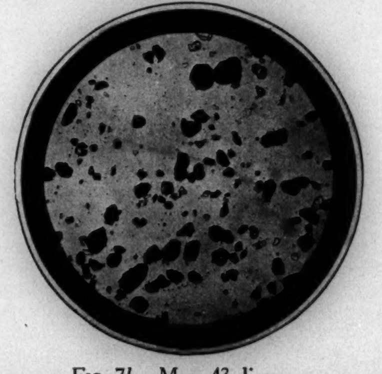


FIG. 7*b*.—Mag. 43 diam.

Corundum is naturally a very hard material, but there is one particular kind which is quite useless as an abrasive, owing to the ease with which it cleaves into flat plates. Its durability is so small that it has no abrasive value.

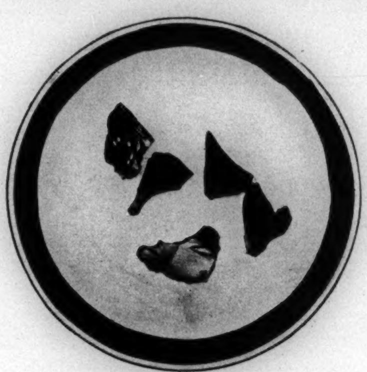


FIG. 8*a*.—Mag. 43 diam.

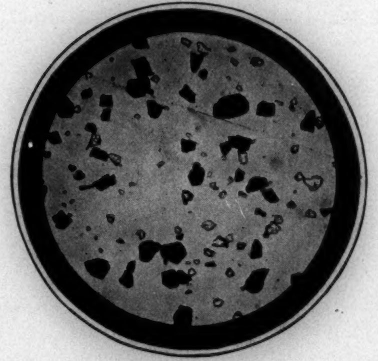


FIG. 8*b*.—Mag. 43 diam.

An abrasive may have no well-defined planes of cleavage, and yet it may break up irregularly. This is characteristic of emery, which is natural corundum containing oxides of iron and other impurities irregularly distributed.

Fig. 7*a* is a photomicrograph, magnification 43 diameters, of a few grains of fresh 3-minute emery, and Fig. 7*b* shows the result of grinding glass with the abrasive for three minutes. The grains have broken down into much smaller ones, which retain, however, the form characteristics of the original grains.

The loss of cut is only temporary. The material after washing can be used as a finer grade of emery. Particular note should be taken of the particles of glass debris, which are small in comparison with the fragments of the abrasive.

Carborundum is an artificial product of great hardness. It has a vitreous appearance, which is clearly visible in the photomicrograph, Fig. 8*a*, previously referred to. Grains of carborundum, when examined by transmission of polarised light, appear highly stressed, the result no doubt of rapid cooling from a high temperature. It is quite to be expected that such grains will break up into smaller particles of irregular shape. This breaking up is indicated in Fig. 8*b*, which shows the result of grinding glass with the abrasive for three minutes. It will be seen that the proportion of glass present is greater than in the case of the emery, and that the particles are small compared with the grains. As before, the loss of cut is only temporary.

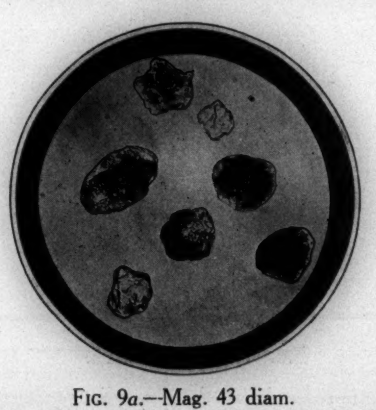


FIG. 9*a*.—Mag. 43 diam.

Owing to its hardness and its other properties, fresh carborundum has at least five times the abrasive power of a corresponding grade of emery, and its durability is also greater.

It would be interesting to know to what extent the durability of the abrasive would be improved by slower cooling of the heated mass from the electric furnace.

Fig. 9*a* is a photomicrograph, magnification 43 diameters, of several grains of Fontainebleau sand. The grains have a rounded, water-worn appearance, and from the abrasive point of view the form is bad.

Fig. 9*b* is a photomicrograph, magnification 43 diameters, which shows the result of grinding glass for three minutes. The sand has broken down to a very considerable extent, but the particles are no longer rounded ; their form from the abrasive point of view is improved. Some types of sand may actually be improved by use. An interesting point to observe is that in size and form the glass splinters are practically indistinguishable from the broken down grains, showing that, as regards fracture, the abrasive and glass are comparable.

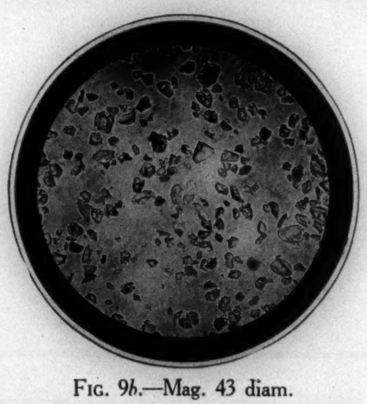


FIG. 9*b*.—Mag. 43 diam.

In all the three typical abrasives illustrated in Figs. 7, 8, and 9 the loss of cut is evidently not due to the change of form. If the debris is washed the abrasive can be used effectively as a finer grade.

When a number of grains are in action the total load will become distributed over a number of points, and the intensity of pressure will be correspondingly diminished. Theoretically the quantity of material removed should be the same, as the number of points in action should be correspondingly increased. In practice, however, the action of the grains is affected by the clogging action of the glass debris, and the loss of cut is often very marked.

In the case of the Fontainebleau sand debris shown in Fig. 9*b*, the total load is carried, not only by the increased number of broken down grains of abrasive, but also by the particles of glass, which are comparable in size. It is the common experience of the workshop that sand very quickly loses its cut.

For purposes of comparison, several diamond splinters are illustrated in the photomicrograph, Fig. 10, the magnification being 16 diameters.

Abrasion depends quantitatively upon the number of points brought into action in unit time, so that the more frequently the grains are brought into repeated action, the greater will be the material removed. It is customary, therefore, to move the grinding tool relatively to the glass, and the amount of abrasion will accordingly depend upon the relative speed of the tool and glass.

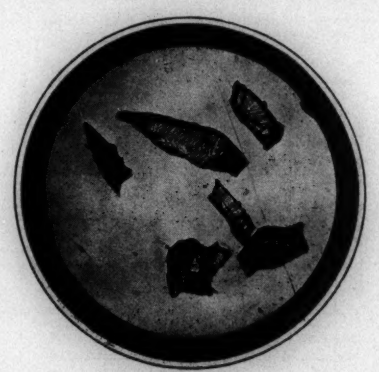


FIG. 10.—Mag. 16 diam.

Neglecting considerations which depend upon the physical properties of the abrasive and the glass, it is interesting to observe that abrasion depends quantitatively upon the load on the tool and upon the relative speed of the tool and the glass.

The effect of load is illustrated in Fig. 11. To eliminate the effect of loss of cut fresh abrasive was applied at intervals of one minute, and special precautions were taken to ensure that the conditions throughout the tests were the same. The quantity of material removed was measured by weighing.

It will be seen that in all the three cases of sand, emery and carborundum the abrasive effect is directly proportional to the load applied.

No other conclusions should be drawn from these curves. They are exhibited only for the purpose of indicating what is the effect of increase of load, under special circumstances.

Fig. 12 shows the effect of increasing the speed of the tool relatively to the glass, all the other factors being maintained constant. The various points fall remarkably well upon a straight line, showing, as was anticipated, that abrasion is directly proportional to speed.

Water, or other lubricant, plays an essential part in the abrasion of glass. If there is too little water the glass will be deeply cut and possibly crack, and if there is too much water the result will be the same, at least so far as the cutting is concerned. Under proper conditions the abrasive should be well moistened with water, the grains being separated from one another by a film of liquid.

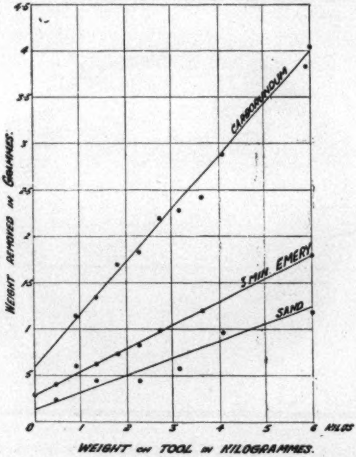


FIG. 11.

One of the important functions of the water is to equalise the temperature over the surface and thus to prevent rapid local rises at the points of action.

If there is too little water, the particles gather in lumps which deeply score the glass. Owing to the absence of sufficient water, the heat generated at the point of abrasion may rise to such an extent that cleavage takes place.

If there is a large excess of water a continuous layer of liquid may exist between the tool and the glass. All air will then be excluded and the load on the tool will be enormously increased. Some particles of abrasive may be forced into the glass or tool; others will be caught by the obstruction and tear the glass deeply as before.

From the above general remarks it will be evident that the question of the abrasion of glass is a most complex one that involves a considerable number of variable factors. The collection of satisfactory data requires much time and great care, if wrong conclusions are to be avoided, but the interest of the results that are obtainable will well repay the time that is spent upon them. Within the limits of a general paper such as this, it is unfortunately impossible to deal as fully with the subject as might be desired.

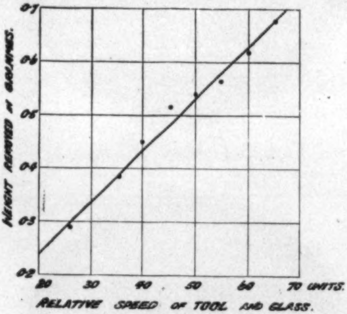


FIG. 12.

Reference has been made in the introduction to the forming of optical parts by means of abrasive wheels. This method, which has been extensively employed by the author for a considerable number of years, is now largely superseded. A brief reference to the system may, however, be of interest.

Grinding wheels in the case of metals are supposed to act by cutting; the sharp edges of each surface grain held in the bond being generally likened to the tooth of a milling cutter. Grinding wheels in the case of glass appear to act by pressure very much in the same manner as a loose abrasive.

Fig. 13*a* is a photomicrograph, magnification 230, of a piece of crown glass ground by means of a carborundum wheel of grit 220 and grade J, the cut being 1/40 mm. and the table speed 3 meters per minute.

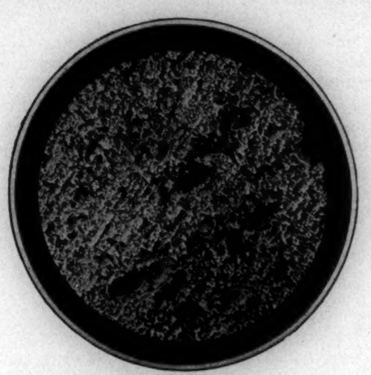


FIG. 13*a*.—Mag. 230 diam.

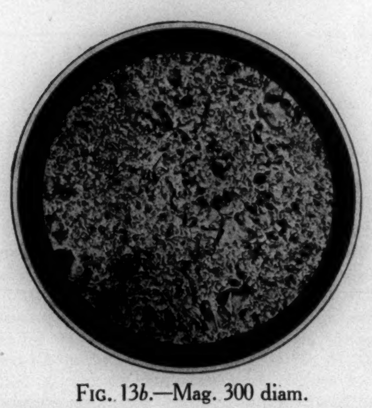


FIG. 13*b*.—Mag. 300 diam.

Fig. 13*b* is a photomicrograph, magnification 300, of a piece of similar glass ground with loose abrasive.

The general characteristics are clearly the same, although in the case of this particular wheel-ground surface there are greater indications of flow.

Quite deep cuts can be taken with an abrasive wheel, provided the table speed is reduced so that the quantity of material removed remains about the same. Thus, a cut can be taken of 1.2 mm., at a speed of 6 cms., or alternatively, 1/40 mm. at a speed of 300 cms. per minute.

For machine reasons the author prefers the high table speed. It is essential that the water supply should be copious, otherwise excessive local temperature will produce cracks.

Before leaving this subject of glass grinding it may be of interest to describe the method devised by the author for comparing and recording the effects of abrasives.

A plate of standard glass is machine-ground under standard conditions, upon a flat tool charged with the abrasive.

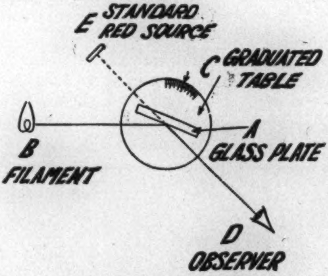


FIG. 14.

If such a plate is viewed so obliquely that the irregularities are foreshortened to such an extent that even the largest red rays are reflected, a perfect white image of, say, an incandescent filament may be seen reflected from the surface. The image will be as clear and distinct as if viewed from a polished silver mirror.

In Fig. 14, A is the ground plate mounted upon a graduated table, C. An incandescent filament or other bright white light is placed at B, at a distance of a meter or more, and the image reflected from A is viewed by the eye or an observing instrument at D. If the plate is rotated so as to reduce the angle of incidence, the eye being moved so as to keep the image central, there will be observed at one point an abrupt change in the whiteness of the image, due probably to the scattering of the more intense short wave rays.

In the first instance some difficulty may be experienced in observing the change, but once it has been observed no difficulty should be experienced in locating the point of change to within half a degree without the use of any special apparatus other than the graduated circle.

If now the angle of incidence is still further reduced, the image will quickly become red and then rapidly fade away. The point of maximum redness can be recorded to within 3/4 degree, but if a standard red placed at E is employed, a more accurate determination can be made.

These two points where the white image changes and the red is a maximum afford a definite record of the surface that is independent of the personal element or the intensity of the illumination.

Repeated measurements within half a degree can be made of the point at which the image disappears, but as these measurements are not independent of the illumination and the person, it is necessary to standardise these factors.

For workshop purposes it is often sufficient to observe this vanishing point alone, and in this way a satisfactory control over the grading of the abrasives can be maintained.

The method is capable of useful elaboration.

In the case of a piece of hard crown glass ground with 3-minute emery, the angles of incidence at the points of change from white, maximum red, and very dull red, were 80°, 78°, and 75° respectively. In a second specimen the figures were 81°, 78°, and 75°.

For the surface indicated in Fig. 13*a*, ground by an abrasive wheel, the figures were 66°, 61°, and 46°.

Polishing.

The finely ground surface is polished by means of a flat tool supplied with moistened polishing material. The tool may consist of a light metal runner having on its working face a substance such as pitch, which can be moulded flat and which will hold the medium. Other materials, such as cloth of various hardnesses, selvyt, paper, fibre, wax, or various compositions, are often used under particular circumstances. For the best class of work it is customary to use pitch tools.

The polishing medium most commonly used is rouge, but there are other suitable substances, such as manganese dioxide and tin oxide. Many of the metallic oxides have important polishing properties. Manganese dioxide is indeed possibly superior even to rouge, but its black colour and adhesive properties militate against its use where the comfort of the workers is considered.

According to Sir George Beilby, when the action of the polishing tool disturbs the surface molecules to such an extent that the cohesive and crystallic forces are overcome, the molecules rearrange themselves in a continuous layer. As stated in my first lecture, this layer becomes broken up and removed. The process repeats itself until a perfect surface is obtained, when the layer passes the bottoms of the deepest pits.

The formation of perfect patches on a rough-ground surface is well illustrated in Fig. 15, which is a photomicrograph of a crown glass surface magnified 125 diameters. A special cloth polisher approaching the hardness of pitch was employed, and on the patch surfaces there are at places slight traces of buffing action. Similar specimens polished with hard pitch show no such buffing.

In the process of polishing there are two very distinct stages, namely :

(*a*) Wet polishing ;
(*b*) Dry polishing.

The function of the first stage is to remove material ; the function of the second is to fill up sleeks. In the language of the shop it is customary to dry up each wet, but under special circumstances the drying-up stage is applied only after a considerable amount of wet polishing.

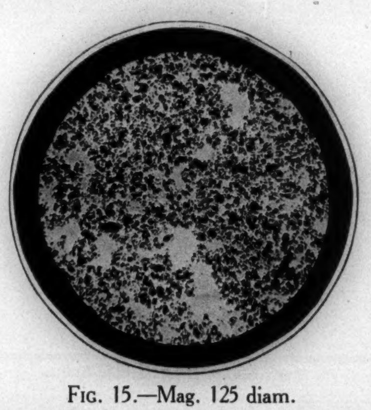


FIG. 15.—Mag. 125 diam.

With regard to the wet polishing stage, the rouge and water is applied to the surface of the tool and is worked over the surface of the finely ground glass. Within a few seconds small, but practically perfectly polished, patches make their appearance when viewed under the microscope. In ten minutes 80 per cent. of the surface may be polished, but several hours will probably be required to remove the deepest greyness.

If the polished patches are carefully examined under the microscope with suitable illumination there will be observed numerous grooves of different depths, the majority being just invisible. The deeper grooves are typical sleeks, the others being possibly embryo sleeks. Frequently the appearance resembles that of a fresh varnished surface over which a fine brush has been drawn.

There seems no doubt that the material from the grooves and sleeks is actually removed and not deposited again in the wet polishing stage. From the average of one large series of measurements, the reduction of thickness of a plate of crown glass during each hour of wet polishing by machine was about seven wave lengths.

Measurement of thickness was found to give more consistent results than measurement of weight in the case of thin plates of large surface, even when the edges were well bevelled, owing possibly to the effect of chips.

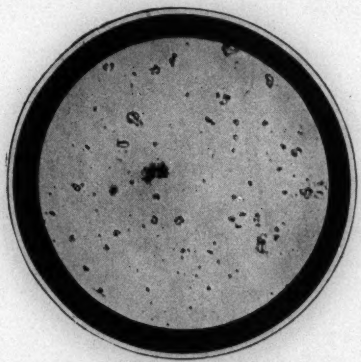


FIG. 16*a*.—Mag. 1,000 diam.

From similar tests made with a thoroughly cleaned old pitch polisher, using water only without any polishing medium other than that embedded in the skin of the polisher, the amount removed was 2.5 wave lengths per hour. The face of the old polisher was glazed and highly reflecting.

In the third series of tests made with a new black pitch polisher containing no rouge and supplied only with water as a polishing medium, the removal of material per hour was two wave lengths.

Throughout all the above tests the tool was kept continuously wet. It was never allowed to become dry. Before each of the above-mentioned tests and those mentioned later, the tools were worked down in every case to the true figure of the surface, so as to ensure action over the whole face.

Specimens of the material removed during the pitch and rouge polishing process have been collected and photographed with some success under the microscope. Fig. 16*a* is a photomicrograph of the glass particles magnified 1,000 diameters. The average size of the particles is about two wave lengths. There are one or two large particles that are evidently groups. Under the microscope these patches could generally be subdivided with ease into small particles. Fig. 16*b* is the same specimen photographed on a black background under the microscope. Each particle of glass transmits the light and the little tails of light are suggestive of the form. The magnification is 600 diameters.

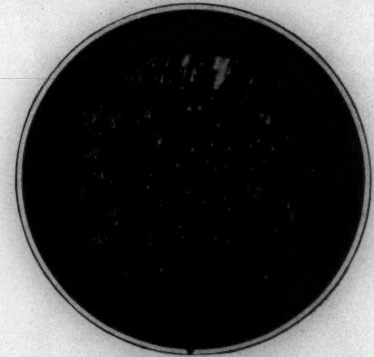


FIG. 16*b*.—Mag. 600 diam.

With regard to the dry polishing, it is customary in practice to dry up the wet, that is, to allow the water to dry and the rouge to be worked out into the grooves provided for it. The glazed pitch surface then comes into actual contact with the glass surface, upon which it appears to exercise a considerable liquefactive effect and drag, as is to be expected. All the minute furrows produced in the wet stage are levelled down and the sleeks are filled in.

The chief function of the operation is to fill in the sleeks and improve the brilliance of the surface.

With one forward and backward stroke by hand over a length of about 15 cms. a transverse sleek having a width of two wave lengths can be filled in. Two strokes are required for one of four wave lengths. In the workshop sleeks have to be classified for some purposes, according to the number of strokes that will be required to obliterate them.

When each wet is dried up the amount of material removed is slightly greater than in the case of wet polishing alone. Thus, in a series of tests with the old pitch polisher already mentioned, using water only during the wet stage and drying up after each wet, an additional 3/4 wave length

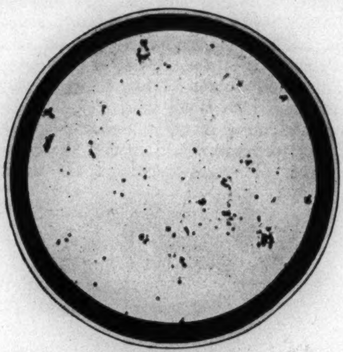


Fig. 17*a*.—Mag. 450 diam.

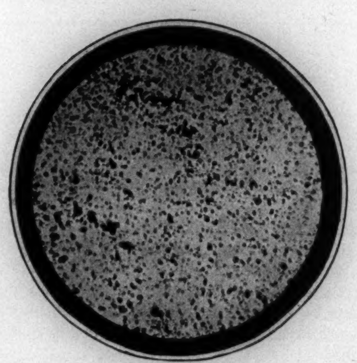


Fig. 17*b*.—Mag. 450 diam.

was removed per hour. The general conclusion is that most material is removed in the wet stage and that a small amount is also removed in the dry polishing stage.

There are many polishing media, the most typical being rouge. Under the microscope it will be seen that the particles of rouge are extraordinarily fine. As individual particles they can have but little effect. To separate them is not easy, as they tend quickly to gather in flat clusters as indicated in Fig. 17*a*, the magnification being 450 diameters.

When the rouge has been worked for a few minutes the clusters appear to gather in rounded lumps, some being extremely small and others larger. The rounded formation is indicated in Fig. 17*b*, the magnification being 450 diameters. The particles in size and form resemble the particles of glass removed in polishing.

It should be observed that the Beta material is ploughed out. The abrasion of the Beta material is of quite a different character from the abrasion of Alpha material where pressure is the essential feature.

It is conceivable that smaller sleeks or fine Beta layer cracks may be covered over if the cohesion of the surface substance is sufficiently great. What the minimum width of the crack must be to escape covering, I do not know. I have reason to think it must be less than two wave lengths.

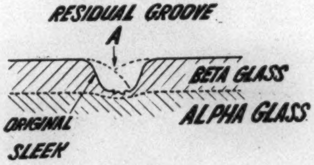


Fig. 18.

The appearance of a sleek under the microscope in the process of being filled in is interesting. As left from the wet stage the sleek has an appearance that suggests the section shown in Fig. 18. When nearly filled in, the appearance under the microscope is suggestive of the dotted section. The small groove that may be finally left is generally invisible owing to want of contrast under the microscope unless the sleek is not well filled.

If the partially filled in sleek, Fig. 18, is exposed momentarily to hydrofluoric acid gas, globules condense along the groove A, and the sleek is reproduced as a series of pools. A well worked out sleek having probably no groove can be reproduced by etching, especially with liquid hydrofluoric acid. Considering the energy expended on the filled in material, the latter is probably more soluble than even the other parts of the Beta layer, and certainly than the Alpha material. Once a portion of the sleek is reproduced, the acid eats its way rapidly along the sleek in both directions.

From the above-mentioned experimental evidence it is possible to build up a probable mechanical theory of polishing.

(1) The agitation of the surface molecules communicates itself to the underlying molecules, thus inducing surface flow.

(2) As indicated in Fig. 19, the rouge in the form of rounded lumps ploughs furrows in the Beta material. Some of the furrows are very shallow with what appears to be raised margins ; others are comparatively deep sleeks.

(3) As the result of the continuous repetition of stages (1) and (2), the surface is reduced below the level of the deepest pits.

(4) In order to obliterate the sleeks, the water is allowed to dry up. The grains of rouge work themselves out or into the grooves in the tool, which then comes into optical contact with the Beta layer. The surface molecules are caused to flow, the shallower grooves are flattened out, and the sleeks are filled up by the flow of the surface material resulting from the movement of the tool.

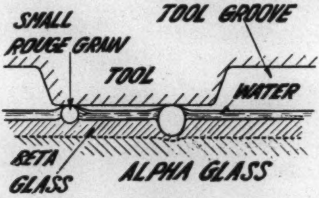


FIG. 19.

In conclusion I wish to exhibit some specimens illustrating the cracking of the Beta layer.

If a hard substance such as the point of a gramophone needle is drawn over the Beta surface of glass, there may be seen under suitable illumination a series of semi-circular cracks through the surface layer. Slight etching widens these cracks and permits of their being photographically reproduced. When the load on the needle is increased, the width of the mark increases, but not in direct proportion.

Fig. 20 is a series of photomicrographs, magnification 43 diameters, of the marks made by means of the gramophone needle shown magnified by the same amount. A new needle was used for each specimen, as it was found that the needle broadened after several tests. The arrow indicates the direction of motion of the needle, which in all cases was towards the convex sides of the cracks. The load in lbs. on the needle is indicated under each specimen.

A wheel rolled over the surface does not produce the marks in question, there being less tendency to chattering.

In seeking for an explanation of the crack formations, the effect of the impact of a steel ball of 3/32 inch diameter was tested. The apparatus employed acted on the principle of a percussion centre punch.

Some of the cracks produced are illustrated in Fig. 21. By suitable regulation of the spring pressure the action could be so adjusted that a clean crack was produced without any central fracturing. Thus, in Fig. 21*a*, a true circle is produced, and also a spiral. No doubt the spiral form is due to a slight displacement of the centre of contact during the action. An opener spiral will be seen in Fig. 21*b*.

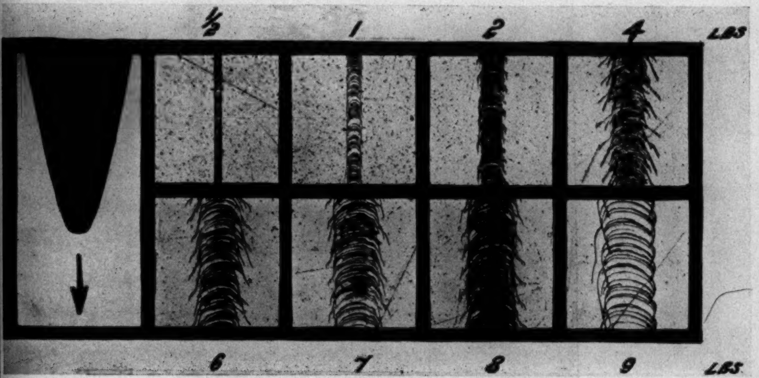


FIG. 20.—Magnification 43 diameters.

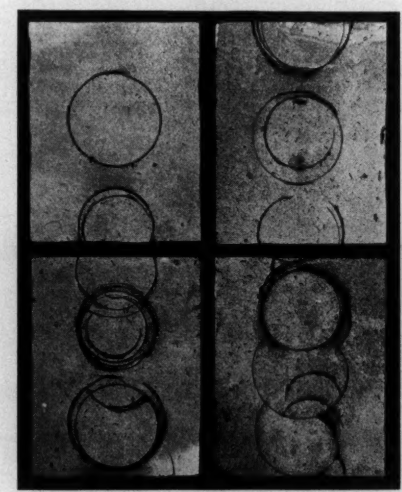
In Figs. 21c and 21*d* some of the specimens were purposely made to overlap. From these specimens it appears that the surface cracks cross one another at places and are terminated at others. Now, if the cracks were due to forces transmitted only through the surface layer, it is to be expected that a crack would be terminated by one of earlier origin. As this is not always the case it would appear that the underlying material plays some part. A possible explanation is that the wave of force originating at the area of contact of the ball and glass is transmitted as indicated in Fig. 22, through the Alpha material, the outcrop at the Beta layer being circular in form.

The regulation of the pressure is such that, although the Alpha material does not cleave, the weaker Beta layer cracks. On this hypothesis it is quite understandable that the surface cracks may cross one another or be terminated, according to circumstances.

If now the needle is moving in the direction C, the Beta layer at A will be in compression and may not crack, while the material at B will be in tension and will crack more readily. Thus a segmental crack concentric with the point will be produced.

In view of the above remarks, there is reason to believe that, contrary to the opinion sometimes expressed, the strength of the polished surface material of glass is considerably less than that of the underlying material.

(*a*) (*b*)



(*c*) (*d*)

FIG. 21.—Mag. 42 diam.

In support of the statement made in my first paper that mechanically polished, fire-polished and glazed fractured surfaces are all of the same type, I have produced similar surface cracks on all types of surfaces, as indicated in Figs. 23*a* and 23*b*.

I have also tested the natural growth light reflecting surfaces of crystals, such as topaz, quartz, copper sulphate, and tartaric acid, without finding any traces whatever of surface cracking or any indication of a Beta layer.

But the mechanically polished surface of a quartz plate, when similarly treated, exhibited all the characteristic cracks.

Natural growth surfaces have, I believe, no Beta layer such as have polished glass, rocks and other materials, but when the surface of the crystal or mineral is due to faulting, a Beta layer would no doubt be formed.

Referring again to the series, Fig. 20, it will be seen that the cracks are segments of circles terminated in some cases by two series of tangential cracks. From measurements it appears that one series is inclined at between 45° and 50° to the axis, and the other at from 5° to 7°. The former series probably represents the lines of maximum shear.

Careful measurements have been made of the diameters of the circular portions. Fig. 24 is a diagram showing the straight line curve obtained by plotting the logs of the diameters with respect to the logs of the loads on the needle. The points lie remarkably well on the curve.

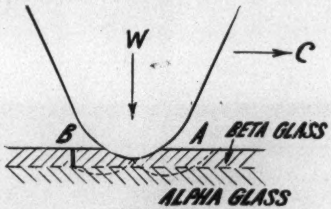


FIG. 22.

From the chart, which shows the results for a particular needle, there is obtainable the relationship $d = w^{0.65}$, d being the diameter in inches and w the load in pounds.

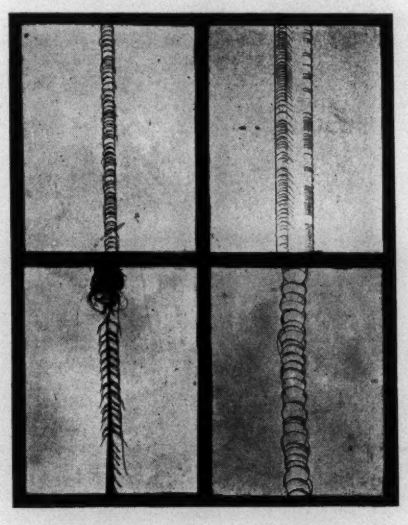
On some of the specimens there will be seen several fine lines. Some of these are true sleeks; the majority are, however, series of minute surface cracks. Under the microscope there is little chance of a true sleek being mistaken for a surface crack. Cracks have been produced by points of various shapes, and in most cases they have the form that could be predicted. Thus Fig. 25*a* is the cracking due to the point of a knife blade and Fig. 25*b* that due to a chisel point.

From a comparison of the size, form, and general characteristics of the cracking of mechanically polished, fire-glazed, and fracture glazed surfaces, I think it is probable that the thicknesses of the Beta layers are in the order given, that is, the fractured surface has the thinnest layer.

This question of the character of the surface layer of glass has an important bearing on a large number of interesting subjects, a few of which only will be briefly referred to, as time will not permit of a fuller discussion of them on the present occasion.

Several substances, such as French chalk and aluminium, have the property of permanently marking glass surfaces. If, for example, the surface is marked very lightly with a French chalk pencil, or one of the other substances, the mark will be distinctly visible, especially when the surface is breathed upon, owing to condensation of moisture on the glass surface and not on the parts covered with chalk. By careful manipulation the chalk can be scraped off and the mark can be entirely obliterated. But if greater pressure is exercised on the pencil, a permanent mark will be formed, however carefully the chalk has been removed.

(*a*) Fire glazed.
2 lbs. 8 lbs.



4 lbs. 8 lbs.
(*b*) Fractured.
FIG. 23.—Mag. 41 diam.

The explanation is, I think, as follows. Owing to its talcous nature the French chalk accumulates on the surface in a hard, glassy mass and adheres tenaciously. The forward motion of the pencil tears the Beta layer in the manner already illustrated and fragments of the chalk may even be squeezed into the cracks.

If a layer of French chalk is deposited on the surface of the glass and a steel needle is drawn over it, the powerful drag will be easily felt. If the French chalk is then removed with sufficient care, the path of the needle will be disclosed. It will exhibit all the characteristic crack formations. If the patch of French chalk is rubbed off with the exercise of considerable pressure, the whole of the underlying Beta layer will be covered with cracks and present a crazed appearance.

In the discussion of my last paper a chemical theory of polishing was advanced by a member, and in support of that theory it was stated "that the behaviour of polished glass surfaces was distinctly different, according to the polishing material used, towards certain chemical reagents." Considering the ease with which large Beta cracks can be produced and the fact that a few fine series of cracks are generally present on most surfaces, even when polished by professionals, I suggest that the substance acted upon by the reagent may have been retained in such cracks.

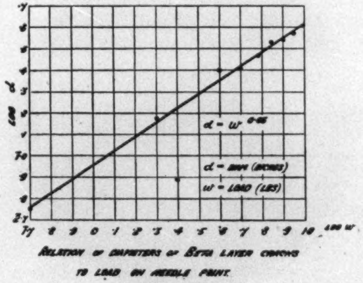


FIG. 24.

It is common experience that if gum, fish-glue, or other similar substances are allowed to dry on the surface of glass, fragments of the glass will be pulled away with the glue. These substances contract greatly on drying, and it is probable that they exert sufficient surface pull, not only to crack the Beta layer, but to extend the crack to the underlying Alpha material. It will be understood that the intensity of stress at the bottoms of such fine cracks must be very great when any force tending to open them is exerted. All my attempts to work out surface scratches by polishing have failed, because, as can be observed under the microscope, the surface cracks extend downwards under the action of the working forces.

It is very probable that the Beta layer of the tension side of toughened glass is peculiarly sensitive to surface cracking, and to the extension of such surface cracks to the Alpha material.

As is well known an ordinary glass tube, if scratched internally, will sooner or later break down. The scratch need not, in the first instance, extend through the Beta layer, and it will generally be quite invisible to the unassisted eye.

There is one more subject to which I wish to refer, namely, the joining of optical surfaces by the very beautiful method recently devised in the laboratories of Messrs. Hilger.

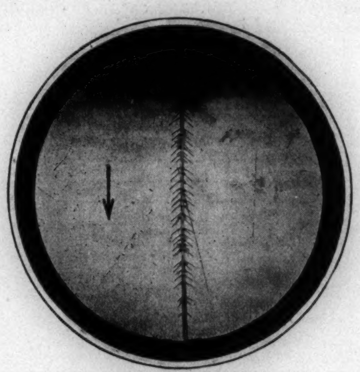


FIG. 25*a*.—Mag. 42 diam.

From the point of view of the optical instrument-maker the method is, I understand, of limited application at present, owing to the necessity of repolishing the slightly distorted surfaces, which are not always accessible, and to the difficulty of joining glasses of different physical properties. But for many purposes the method must have an important application.

May I therefore suggest the following possible explanation of the joining action? :—

The glasses to be joined must be approximately the same, and the polished surfaces must be in optical contact. The parts are heated to a temperature of about 100° C. less than the softening temperature of the glass. At this temperature the Alpha glass is not readily deformable, but, as illustrated in my last paper, the Beta layer most probably is. Actual welding of the surfaces accordingly takes place.

DISCUSSION.

Mr. S. D. Chalmers said Mr. French had brought forward a good deal of very valuable experimental evidence. Any criticism of the paper would be directed to the conclusions drawn rather than to the experimental methods and results.

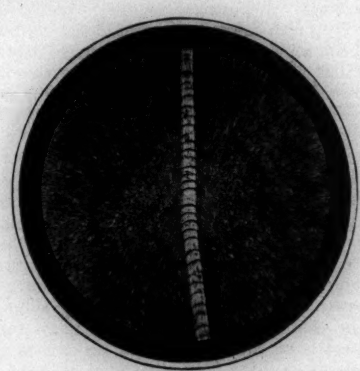


Fig. 25*b*.—Mag. 42 diam.

Many of Mr. French's results seemed to him not inconsistent with the theory that the action of the rouge was to a considerable extent chemical; when the rouge was forced into close contact with the glass it was dissolved in the glass, reducing the softening point and so making it easier to produce a more fluid layer. In the earlier stages it was desirable to liquefy the tops of the hills and to roll these off as small globules, and this was probably very easy. As larger areas became polished it was more difficult to remove the upper layer, as the surface tension would tend to become even over each separate patch.

Until the bottoms of the deepest pits had been reached by the pitch polisher, it was not possible to make a completely continuous surface layer.

The evidence with regard to the glazing over of sleeks seemed to indicate that as soon as there was a quite appreciable area of surface in a modified state, then there was a semi-plastic layer which could be modified and changed. So that it seemed to be borne out by Mr. French's work and his experimental evidence that the object to aim at in polishing glass was first of all to remove all those portions of the glass which were not required by methods which enabled it to be got rid of as soon as possible, and that the treatment with the rouge and with the pitch should be in the direction of simply removing all the upper points, but that as soon as the actual adaptation of the remaining layers to the purpose of optical work had been accomplished, the character of the polishing should be changed and the flow of the rest of the surface should be brought about as quickly as possible.

He had been very much interested in Mr. French's method of determining the actual character of the surface—the actual depth of the ground surface that was left after the grinding. Endeavours had been made on more than one occasion by himself to judge the value of the smoothing of a surface by observing the redness of sources of light, and he had on more than one occasion deliberately worked surfaces to a greater degree of fineness in the smoothing process with the object of being able to utilise a red light while there was still no appreciable polish upon the surface, and it was quite remarkable how good an image could be obtained. The great value of Mr. French's method was that numerical values could be obtained. He was quite sure from his own experience that Mr. French's method must be a most valuable one of ascertaining just how fine the surfaces really were, and he should certainly endeavour to make use of it in any future experiments he might make upon the subject.

In conclusion, he would like to suggest that when this subject next came up for discussion an invitation should be sent to the foremen of the various glass factories. He knew that a great many of them were very much interested in these methods, and some of them might make valuable contributions to their discussion, particularly in the case of some of the old microscope lens workers.

MR. C. B. USTONSON said there was one point on which he would like more information, namely, the influence of the weight on the tool in the degree of difference of heat generated. That surely must make quite a considerable difference. For instance, if a tool was used and the polishing was done with the aid of water, that must naturally be very much cooler than when allowed to dry. He would like to know if any experiments had been carried out to ascertain the difference in temperature necessary to obtain quicker polishing.

DR. WALTER ROSENHAIN considered that the paper contributed by Mr. French on the present occasion was an extremely valuable addition to that which he had presented to the Society a few months ago; and it was particularly valuable in that it contained a large quantity of experimental fact of really very considerable accuracy, and, no doubt, of very great practical importance. The whole point of the paper, he thought, lay in the fact that it brought to bear methods of scientific observation and measurement on a fundamental process in optical manufacture, which certainly in the past had not received that amount of accurate study and attention which it undoubtedly deserved.

Mr. French's paper as it stood really consisted of two parts. In the first place it consisted of experimental fact and practical results, which were unquestionably of high value; and in the second place it consisted of theoretical explanations and deductions, which he thought were open to a very great deal of question. The paper started by enunciating a series of propositions, and one was naturally led to expect to find those propositions established in the course of the paper by experimental proof. That expectation, however, was not found to be entirely justified when one came to the end of the paper. One was interested and charmed by a large variety of important and most interesting data, but their particular bearing on the propositions enunciated at the outset was in many cases not very evident.

The Theory of Polishing.

For instance, Mr. French enunciated the statement that there was no covering of the pits; yet afterwards he showed that sleeks were filled in by flow. All he could say was that, to a large extent, the theoretical view of polishing which Mr. French had put forward in the present paper was much more acceptable to himself than that advanced in his previous communication; he came a great deal nearer to the fact that the final covering over of the irregularities left in the earlier stages of polishing were due to flow of the surface layer. Whether or not such flow could actually bridge a small hole or cavity was simply a matter of experimental fact; personally he had seen such cases of bridging over, and others would no doubt bear that out.

Quite apart from these questions of theory, there were one or two interesting points brought out by Mr. French with which he would like to deal. For instance, he gave a diagram showing the action of a grain of abrasive in chipping off flakes of glass. He (DR. ROSENHAIN) had shown an experiment, in a lecture before that Society some years ago, which consisted in taking a piece of glass with fairly smooth surface and dropping upon it a small weight, which might have been a steel ball such as Mr. French described, and what happened in that case was the formation of a fracture cone, no doubt representing approximately the planes of maximum shear, but not exactly, because the surface was never smooth but always corrugated with a particular corrugation which had a perfectly definite wave-length. He thought what happened was that a system of stationary waves was set up which added to the shear in such a way as to produce a surface of maximum shear which was not conical but corrugated. Now it was possible to regard the whole abrasive action with a loose abrasive in rather a different light, and in what he thought was perhaps a more probable light than the one adopted by Mr. French, namely, that this was of the nature of a series of blows struck by projecting corners of the abrasive as the particles were thrown or pushed about between the tool and the surface of the glass. What happened was that the successive cones met each other, and the crack formed became converted into a chip by the arm of the next fracture cone, and so on. Of course, a good deal depended upon the particular abrasive used and the kind of shape it favoured.

Abrasion of Tools.

There was another point which Mr. French's view rather neglected, and that was that a cast iron tool and such an abrasive as carborundum or emery showed quite an appreciable abrasion of the tool as well as of the glass. To some extent, particles of the abrasive would become temporarily embedded in the tool.

He had been interested in the photograph of the surface which had been ground with a wheel, and he thought there was no doubt at all that what they had there was really a series of grooves or scratches which had chipped out—splintered out. There was a very distinct sign of direction about the grinding in that case, markedly different from the appearance when the grinding was done with a loose abrasive.

There were apparently, according to Mr. French's view (and he thought he was perfectly correct in this respect) three actions—a grinding action, which consisted purely in the splintering away of small particles of the surface of the glass; then the first stage of the polishing action, the wet polishing, which, according to Mr. French's view (and again he thought he was probably quite right in that view) consisted also in the removal of particles of glass by what he called the "ploughing" action of the rouge, or other polishing material; and finally there was the true polishing action, which consisted in the flow produced by the dry polishing. But would it not be possible to improve matters if they could get something intermediate between that ploughing action of the rouge and the splintering action of even the finest emery? The removal of matter by means of rouge ploughing must necessarily be slow, and uneconomical mechanically. If something could be obtained harder than rouge but very much finer than the finest emery now used—something which would plough, but plough very much more vigorously than rouge, he believed it ought to be possible to accelerate that part of the operation very materially, and leave the rouge, or some fine substance such as that, merely for the last stage, the equalising of the surface irregularities—what Mr. French called sleeks—by the production of flow.

There was another point, a minor point, which he might mention incidentally; namely, Mr. French's very interesting reference to the behaviour of carborundum in breaking down, which Mr. French considered to be due to internal stresses arising from rapid cooling. If that was the case, it ought to be possible to *anneal* the carborundum before use. Whether that would pay or not he did not know, but it would be quite an easy experiment to try, and it would be very interesting to see how the carborundum behaved after such treatment, and whether it broke down more or less rapidly than the ordinary crystals.

Analogy to Behaviour of Metals.

Finally he would like to point out that the ploughing action of the rouge in the last stage of the wet polishing, the final flowing action of the Beta layer during the dry polishing, and the behaviour of the filled-in sleeks on etching were very closely analogous to the behaviour of the harder metals when polished in a similar manner. Mr. French seemed to think there was a fundamental difference between the behaviour of glass and metal, and yet, if they read his description, they would see it agreed almost word for word with the description of the polishing process applied to metal as given by Sir George Beilby.

There was one distinction which he thought was important, and which he thought Mr. French had missed. He seemed to think it surprising that the surface layer of the glass should be weaker than the rest of the glass. Perhaps he based that idea on the view freely expressed (and he thought perfectly correctly) that in a metal the amorphous surface layer was stronger and harder than the crystalline material beneath it. On the other hand, in glass they were not dealing with a crystalline material beneath, but with a vitreous material, and they were comparing, not an amorphous surface with a crystalline body, but an amorphous surface layer formed under severe stress with an amorphous vitreous body "congealed" by gradual cooling; so that it was not surprising that the surface glass might be weaker than the congealed amorphous body beneath it.

Chemical Behaviour of Surfaces.

Mr. French had referred to a point which he (Dr. Rosenhain) had raised in the discussion on the previous paper, as to the chemical behaviour of polished surfaces being different when treated by different polishing materials, and he had given a most ingenious explanation of that difference. But he was inclined to doubt whether Mr. French's explanation was the true one. It was, of course, extremely difficult to say how far the polishing material might be present in these minute cracks in the Beta layer, but the action to which he (Dr. Rosenhain) had referred was that of the moisture of the atmosphere and the general tarnishing of the surface. The evidence upon which he had based his statement was largely this—that if pieces of glass were taken of a kind which was fairly sensitive to atmospheric deterioration, and polished with different media—rouge, magnesia, tin oxide, alumina, and two or three others—and the specimens so treated were placed alongside each other and exposed to the same conditions, it would be observed that there was a distinct difference in the rate of tarnishing and atmospheric corrosion; and he doubted very much whether the mere presence of these different polishing materials in minute fissures would really account for that difference of behaviour. It might be so, but he thought it hardly likely.

With those remarks he would leave the matter, and he would only say again that he thought Mr. French had rendered a most valuable service to the whole industry and to the scientific knowledge of the behaviour of glass, by his work, and that the manner in which he (Dr. Rosenhain) had dealt with it was only an expression of his appreciation of that fact.

Mr. A. E. Conrady said he had been extremely interested in both the first and second papers of Mr. French, but he would like to study the second paper much more in detail before committing himself to any remarks on either of them. The process of polishing was a very difficult one to follow, because they were dealing with surfaces which were already very near the limit of microscopical vision, and were dependent very largely on speculation in trying to interpret what took place. On the whole, he did not feel that at present he wanted to commit himself.

Dr. R. S. Clay said it seemed to him, referring to Dr. Rosenhain's remarks as to the analogy between metals and glass, that the real difference was not in the final but in the initial stage. In the removal of metal by any machine, whether milling, planing, or lathe, the metal was removed in a more or less continuous shaving, whilst in the case of glass advantage was taken of the brittleness of the material to splinter off large pieces, and in that way it was removed, in proportion, very much faster than would be possible by a mere ploughing action.

He had been very much interested in what Dr. Rosenhain had said about his fractures, but it seemed to him, judging from the experiments and photographs Mr. French had made, that in the case of glass the fracture was rather of the same kind as the old flint-users, our pre-historic ancestors, made use of in fashioning their flint instruments, namely, the production of a conchoidal fracture by pressure at a point. It would be settled by the shape of the flakes obtained. Dr. Rosenhain's explanation would result in cone or wedge-shaped flakes, but if the surface was left with hollow fractures and the pieces which broke off had corresponding convex surfaces, then it would be more in accordance with the explanation given by Mr. French.

The Alpha and Beta Layers.

He was not quite sure that he followed Dr. Rosenhain in his suggestion that one might be able to expedite the polishing by some method intermediate between fine grinding and wet polishing, if the explanation of polishing brought forward by Mr. French was accepted. He understood Mr. French to say that in the first stage of polishing with rouge one was working entirely in the Beta layer, and that the difference between the fine grinding in the first stage and the polishing was that in the fine grinding one was flaking off the Alpha layer and producing the Beta layer merely by an accident of the process, while in the wet polishing Beta layer only was removed, new Beta material being produced at the same time. The Beta layer appeared to be soft enough to be removed by a sort of ploughing action without splintering. If he was right there, he did not see how it was possible to avoid the jump from the fracture method of grinding to the wet polishing where fractures were no longer being produced, but where one made use of a kind of removal which was much more analogous to the ordinary working of a metal. The final dry polishing process for glass would appear to correspond very much to the polishing of steel, in which the surface was improved by a flow of material, the molecules sliding over one another retained by cohesive forces but re-arranging themselves under the applied pressure.

Mr. P. F. Everitt said that, as he understood Dr. Rosenhain's proposition, he wanted something to take an intermediate position between removal by fracture and the present method of polishing—a new intermediate polishing method which would remove material by scraping without the production of any Beta layer whatever.

Dr. Rosenhain said what he was really aiming at was a medium which should be intermediate in its action between the fracturing action of the finest emery now used and the ploughing action of the rouge—something softer than emery and harder than rouge, and combining the action of both.

Electrification.

Mr. Everitt, continuing, said when glass was rubbed in the ordinary way with a grinding material, a certain amount of electrification always took place, but if there was moisture about, it leaked away. He did not know whether that had anything to do with the questions which arose in connection with polishing, but he thought it might be worth while for someone to investigate what happened to the electricity which was produced and which leaked away directly, so as to see whether that had any bearing on the problem.

Mr. H. R. Fairbanks said that in all Mr. French's experiments he had shown how a very fine, accurate surface was produced. It could be seen, right through his paper, that he was after a first-class surface. He did not think that the suggestion of roughly polishing off a layer in the first place, and then finishing it with a pitch polisher, was of very much use or saved time. It was in operation in some places, but he thought it did not save time. A surface was got as quickly by using pitch from start to finish, and there was more certainty in that way of getting a first-class surface.

Mr. W. Anderson said he had polished glass for more than half a century. The question of sleeks was a simple one. Sleeks were produced by polishing powders, when the polisher was getting rather warm; otherwise sleeks should not occur when the wet process was used. They were produced by a bit of hardened surface of the powder used in polishing.

The **President** inquired whether in Mr Anderson's experience it was possible to wet-polish without producing sleeks.

Mr. Anderson replied in the affirmative, but added the proviso that the polisher should not be old. A new polisher would never produce sleeks, nor would one of moderate age; but it would if it were old and had a hard surface.

Mr. G. S. Dey said that, although he was a stranger, he might perhaps be allowed to say a word or two as the result of practical experience. (The **President**: Hear, hear.) Incidentally, he might mention that he was superintendent of one of the largest optical manufactories in America, that of the Eastman Kodak Co., and had been connected with others, running perhaps as high as 10,000 spindles daily.

There were a number of points in the discussion in regard to which he could not altogether agree. One of the first statements made in the lecture related to the coarser abrasives; it was said that the material acted purely by impact rather than by a sharp cutting action. He believed there was a certain amount of cutting action—not exactly as in the case of metal, but it could be seen very readily where coarser abrasives were used; a single piece of the abrasive became embedded in the tool, dragged around, and cut a continuous striation, and that continued even in the finer grades of grinding.

Difference of Polishing from Grinding.

The questions of polishing and of abrading or grinding were certainly two different questions; the operations were two different operations, and were produced in a different way. It made no difference how fine the grinding material might be; emeries might be used and washed, and used and washed again and again, and their action was still a grinding and not a polishing action, although the material itself might be comparable in fineness to rouge, as far as microscopical inspection was concerned; there would still be a grinding action which was clearly discernable under the microscope. But it had been his experience that the cutting action of emeries did depend upon the sharpness of the grains, and that the action was largely dependent upon the scratching action of many sharp points rather than the percussive action of perhaps a rounded edge grain. What he meant by that was this: that emeries which had been crushed by a crushing machine, and not reduced to fineness by grinding glass, would cut faster and remove more glass material. It was the result of his experience of plate glass grinding, that a new emery which had just been broken down by the mill and graded would cut much faster than an emery which had broken down in actual work, and then been re-washed to the same size of grain and prepared for cutting again. Of course, there might be in the rewashed emery some detritus from the glass previously ground. It was his belief, as the result of at least fifteen to twenty years' experience of glass-polishing, that the action of polishing was largely akin to a chemical or electro-chemical action.

He thought the paper a most excellent one, and he had appreciated it thoroughly, but he could not help thinking its author had assumed the existence of the Beta material and then tried to account for it, rather than endeavoured to prove that there was such a material. He thoroughly believed that there was a flowing action, but it was probably caused by the chemical or electro-chemical action of the rouge or oxide which was used on the glass.

As to the Beta Material.

He would like to ask whether there was in existence a Beta material which was assumed to be necessary to polishing. This had not been specifically stated that night, but he assumed the general inference was that such a material existed and was a necessary element in glass polishing, and that part of the operation of polishing was by the flow of that material.

He agreed with Mr. Anderson that polishing could be done without the production of sleeks. That opinion also was based on many years' experience. He was thoroughly satisfied that polishing could be done without producing sleeks; but he thought it was also true that glass which was perfectly finely polished could be etched and would still show what apparently were slight scratches. But if the assumption was that the Beta material was part of the action of polishing, then what occurred when glass was polished as in the case of cut-glass work, where the polishing was done chemically? Was a Beta material produced there?

The **President**, in closing the discussion, said they must all have one cause for regret, and that was that Mr. French himself was not present to understand the appreciation and pleasure with which the reading of his paper had been received, and to reply to the criticisms which it had evoked. He was quite sure, however, that he would be delighted when he learnt that his second paper had received the amount of attention that had been devoted to it. There could be no doubt as to the value of a paper of that kind. (Hear, hear.) The great merit of such a paper was the sure foundation of experiment upon which it was based. They had now got experimental facts before them, based upon a very long and varied experience of glass-working operations. He was sure Mr. French himself would agree that as far as the experiments themselves were concerned, they stood upon a different basis to those theories which he had based upon them. There were many points about the paper which struck one as being novel, but there was one which had particularly struck him, and that was the exceedingly ingenious and simple method which Mr. French had adopted for the purpose of determining the order of fineness to which his grinding operation had proceeded. While listening to that he had been reminded that it was just about a century since Fraunhofer, in making his famous investigations on the interference of light produced by a parallel beam of light striking normally upon a striated surface, came to the conclusion quite incidentally that his experiments proved that the microscope could never differentiate between two features of an object which happened to be more than a wave-length apart. Now Fraunhofer of course was dealing with normally incident light, and for normally incident light Fraunhofer's conclusion was the conclusion of to-day; it is still the theory of microscopic vision. Fraunhofer of course did not consider the question of light which was incident at an oblique angle—say anything up to 90°—otherwise he would with equal certainty have come to the conclusion that under the new conditions the limit of resolution was half a wave-length. This is still the accepted limit of resolution, only since Fraunhofer's time we have discovered that we can reduce the wave-length of the light concerned and thus increase the resolving power of the microscope, by enclosing the object in a dense medium such as Canada balsam and interposing oil between the front lens of the objective and the cover-glass. In these so-called immersion objectives the limit of resolution is half the wave-length in balsam of the light employed.

Programme for Next Month.

The President proposed a vote of thanks to Mr. French, which was enthusiastically accorded. He also announced that the next meeting of the Society would be held on Thursday, 8th March, when the following communications would be considered :—(1) "A Simple Method of Determining the Size of Tool required for a given Block of Lenses," by Mr. C. L. Redding; (2) "The Design and Testing of Telescope Objectives," by Mr. P. F. Everitt.

The meeting then terminated.

AUTHOR'S REPLY TO DISCUSSION

On "More Notes on Glass Grinding and Polishing."

Mr. French writes :—I am very glad that my paper has received the consideration of so many of the members, and has called forth so much expert criticism.

In reply to Mr. S. D. Chalmers, I think that the advocates of a chemical theory of polishing should advance some experimental evidence in support of so attractive a theory. If the rouge is dissolved in the surface layer, it should be possible to detect it by suitably treating a polished surface in comparison with an unpolished surface of the same piece of glass. Can iron be detected in the surface? Again, rouge is only one of many polishing materials. Are all these materials soluble in the glass? For example, it is possible to polish glass by means of silica. Is silica soluble in glass? These are questions that can be decided by experiment. Personally, although I think the evidence is in favour of the mechanical explanation of the liquefaction of the surface, I do not think my general conclusions are at all dependent on the nature of the forces which increase the mobility of the surface molecules. The assumption that such increase of mobility does take place was merely the starting point of my remarks, and I accepted Sir George Beilby's mechanical explanation as being the one that best accorded with the evidence.

In reply to Mr. Ustonson, anything that will increase the mobility of the surface molecules should increase the rate of polishing. Below a temperature of 300° C. the mobility of the molecules of a piece of crown glass is negligible. At about 700° the mobility is such that the molecules rearrange themselves readily under the action of gravity. At about 900° C. the mobility is so great that a surface becomes fire-glazed. As the temperature in polishing will never be considerable, the effect on the mobility is probably inconsiderable so far as the Alpha material is concerned, but the properties of the Beta material may possibly be such that a small variation of temperature combined with mechanical agitation may have an important effect on the mobility. To obtain consistent results on the lines indicated is very difficult, but I hope to be able at some later date to supply the information Mr. Ustonson desires.

In reply to Dr. Rosenhain, I think he has misunderstood the scope of the second paper. Its function was not to prove the series of propositions enunciated at the commencement of the paper. These propositions were those dealt with in the first paper, and as was explicitly stated they were briefly prefaced to the second lecture for the purpose of avoiding unnecessary repetition later. The first lecture dealt with the relationship of the Beta layer to the Alpha layer. The second dealt principally with certain features of the Beta layer. As the material for the second paper was already in my possession when the first was written, it is unlikely that I would advance contrary views in the two papers as Dr. Rosenhain appears to suggest.

Dr. Rosenhain states that, "whether or not such flow could actually bridge a small hole or cavity was simply a matter of experimental fact." My experimental evidence, as described in the first lecture, shows that gaps in the Alpha material having a width of two wave lengths or more are not bridged over by the Beta layer. If Dr. Rosenhain or others have observed such bridging over, it is desirable that their experimental facts should be published.

With regard to the alternative theory of abrasion advanced by Dr. Rosenhain, the first portion was already dealt with by me in the description of Fig. 5, where the effect of the motion of the tool is considered. With regard to the second part, while it is true that the pressure of a sphere may give rise to a cone fracture, it is rarely the case that the pressure of a grain does so in the ordinary abrasion of glass. Generally a number of conchoidal splinters are formed. With care, complete splinters can be recovered, and very frequently their surfaces are free from the wave formations so often observed under other circumstances.

In discussing the photograph 13*b*, of a wheel ground surface (page 20), Dr. Rosenhain has, I think, missed the real point of the question. Of course the regular recurrence of high points of the rotating abrasive wheel gives rise to distinct signs of direction on the surface. The point of interest is that the wheel ground surface and the loose abrasive ground surface show the same conchoidal fracture features combined with the same surface flow rounding of the fracture edges.

With regard to the paragraph headed "Analogy of Behaviour of Metals," the reason why my description of the polished surface layer of glass so closely agrees with Sir George Beilby's description of the surface layer of metals is the very simple one that my description was intentionally based on Sir George Beilby's. It was my starting point.

If Dr. Rosenhain cannot see where the essential difference between the behaviour of the Alpha and Beta glass material and the corresponding materials in the case of metals, comes in, I can only refer him again to my two lectures on glass and to those of Sir George Beilby, particularly his lecture on the "Transparence or Translucence of the Surface Film produced in Polishing Metals" as read before the Royal Society in 1914.

The question of the strength of the surface layer of glass was emphasised because I have so often heard the statement made that polishing a glass surface hardens it.

With regard to the Chemical Theory of Polishing, is Dr. Rosenhain aware of the persistent films left by such substances as rouge on the surface of polished glass? The chemical theory of polishing is an attractive one, and I personally am not neglecting it. So far I have not succeeded in obtaining any conclusive evidence of such action, and, therefore, meanwhile I have adopted Sir George Beilby's description of the action.

In reply to Dr. Clay, it is possible to recover whole flakes which have the characteristic conchoidal form. Sometimes the surfaces are interrupted, but very frequently they are quite smooth. So far as my observations go, there is but little evidence of simple cone or wedge-shaped flakes, in the case of ordinary abraded surfaces, but under other conditions I have obtained symmetrical fractures of conical, paraboloid, and other forms. Further, I have a specimen of a cone fracture which is so far extended as to show conchoidal spreading of the base of the cone. Dr. Clay has stated my main arguments with much clearness and conciseness.

With regard to the question of obtaining an abrasive between emery and rouge, there are such materials. If time permits, I hope at an early date to submit to the Society some information regarding the comparative abrasive and polishing effects of various materials, with respect to glass.

In reply to Mr. Everitt, I have no information as to the effect of electrical disturbance of the glass molecules, if any exist. The inevitable presence of water must make the problem a very difficult one.

With Mr. Fairbanks I agree entirely, when first-class surfaces are concerned, and in optical work the surfaces should all be first-class, as there is so little extra work involved in the production of the good surface.

Mr. Anderson's remarks are very interesting. But although, as he states, sleeks should not occur when the wet process is used, they unfortunately do. In the case of a large surface, it is difficult to avoid entirely some serious sleeks, which may be caused not only by a hard powder flake, but by any fine particle such as a minute pitch fragment or a glass particle from the broken edge of a minute surface airbell.

In reply to Mr. Dey, if the continuous striation referred to is examined under the microscope it will be seen to be of the conchoidal type, resulting from the pressure of the impact. That particles of abrasive are translated over the work by the tool is undoubted. The purpose of Fig. 5 (page 12) was to explain that even in such a case there was no true cutting such as one meets with in metals, and that the removal of the material was due to conchoidal fracture resulting from the pressure of impact. As I have not yet succeeded in obtaining an emery comparable in grain with rouge, I cannot contest Mr. Dey's statement regarding the continued pure abrasive action of such fine emery. But from the evidence already in my possession I am inclined to differ from him. I hope to deal with this interesting question at a later date.

With regard to the question of sleeks, those of serious depth are more or less accidental. The great majority are mere corrugations of the surface difficult to observe even under the microscope. Does Mr. Dey in polishing pass into the dry stage? If so, why? When the surface of glass is etched with a smooth etching medium I do not think there is any surface layer produced, just as in a natural growth light-reflecting face of a crystal there is no observable surface layer. The reason why a smooth etched glass surface appears polished has been discussed by Lord Rayleigh and others.

I should have been glad if some of the members had dealt with the various points raised at the conclusion of my paper, such as the marking of glass with French chalk. In this connection I wish to refer once more to the welding process of Messrs. Adam Hilger, Ltd. From an examination of the exposed surfaces I find that the distortion is remarkably small and much less than I anticipated. I hope, therefore, it will not be long before Messrs. Hilger are able to extend a process of so much interest and value.

In conclusion, I wish to thank the members for the interest they have taken in the subject of my papers, and to thank the President for his very kind remarks, which I greatly appreciate.

The Optical Society is an active and progressive one, and I do not, therefore, think I need apologise for having raised so many controversial points. I feel that the vigorous discussion of such questions can only have a good and stimulating influence on the optical industry, the advance of which is desired so much by all of us.

OPTICAL ABSTRACTS.

"A PORTRAIT OBJECTIVE WITH THREE SEPARATED LENSES," by Dr. A. Kerber. (ZEIT. FÜR INSTR., November, 1916.)

This paper is concerned with the calculation of an objective of large aperture (*f*/5) of the Cooke type, in which the first separation is somewhat smaller than the second, and in which the positive members have approximately equal focal lengths. The treatment is mathematical, and is developed along the lines of a modification of Seidel's formulæ previously communicated by the author to Zeit. f. Instr. (35, p. 27, 1915). Nothing more elaborate than a general outline of the method can conveniently be attempted here, and for further details of the analysis the original paper should be consulted. The author commences with expressions for the two chromatic and the Petzval conditions, which, for small apertures and fields of view, should be equal to zero. Owing, however, to the existence, when larger apertures and fields are contemplated, of zonal errors it becomes necessary to introduce small changes in the constants of these equations. Considerations determining the magnitude of such variations follow, and, with the assistance of the fundamental formulæ (loc. cit.), an approximate form for the lens is evaluated. Subsequent trigonometric calculation reveals the existence of outstanding aberrations, which are then further reduced by adopting slightly modified values for the Seidel sums. Having thus arrived at a second approximation to the form of the lens, and before dealing more closely with the trigonometric examination of the whole field, the author discusses, with the assistance of the fundamental properties of entrance- and exit-*lukes*, the size and shape of the entrance pupil for oblique pencils. Diagrams are included showing graphically the effective aperture of the lens for semi-fields up to 15°, together with curves exhibiting the spherical aberration, coma, and astigmatism at large apertures.

R. W. C.

"BRITISH OPTICAL SCIENCE." (NATURE, 1st March, 1917.)

The following paragraph is taken from a report on national instruction in Technical Optics, published recently under the auspices of the Board of Scientific Societies:—

"A further need, which is urgent, is the supply of standard text books dealing with those parts of Optics which at present are greatly neglected in this country; this includes practically the whole of Geometrical Optics and a large part of Technical Optics. In our opinion, the quickest and most effective method of dealing with this requirement is by publishing translations of existing foreign books and abstracts of important papers on the subject." The recommendation contained in the last part of this extract is admirable if carefully carried out, and applies to all substantial scientific literature, as well as to Geometrical Optics. But the reason assigned, though doubtless prompted only by our national habit of self-depreciation, is unwittingly a reflection on the numerous treatises on the subject, some of them of high originality, and of Continental repute to judge from references to them, that exist in the English language. If the reason advanced had been that many of these treatises are weak on the technical side, which is important, not on account of scientific principles, but solely or mainly through its connection with workshop practice, it would have struck the mark. It is in British optical manufacture, not in British University instruction and discovery, that there has been lack of appreciation, until recent years, of what organisation, and co-operation between theory and practice, can do, and have done in other countries. It is in the trade that we have fallen behind, for the usual reason that it is easy and profitable to hold an agency for an efficient and pushing foreign organisation, but quite another matter to compete with it. The works of Heath, Herman, C. S. Hastings, Schuster, R. W. Wood, and many others dealing with Geometrical Optics (not to mention the encyclopaedia articles of Lord Rayleigh and other writers) do not seem to be in any way inferior to Continental books, themselves not very numerous; as regards the substantial number of recent works on the technical side of the subject by English and American writers, I am not much in a position to judge, for the reason indicated above, but I see no ground to doubt their value. Nor, within my own knowledge, is there any ignorance of the higher development of Geometrical Optics in such a technical school as the Northampton Institute at Clerkenwell.

In fact, one may be pardoned for what otherwise might seem an invidious remark, that in the vast expansion of Optical science and practice during the last century this country has had more than its share. The evolution of the spectroscope, the mightiest modern weapon of astronomical and ultimately physical research, has been effected mainly in England and America; names such as Rayleigh, Rowland and Michelson at once occur to mind. For a long period the construction of the great telescopes of the world was a British and Irish speciality; it has now gone largely to America, because it is there that they are wanted. One need only glance at the references in Czapski's admirable book—itself an excerpt from a German Encyclopædia of Physics—to see that the treatment of aberration was set on a scientific basis mainly by J. Herschel and Airy and Coddington. The early theoretical work of Roger Cotes and R. Smith was, indeed, largely anticipated in Holland by Huygens; but one can imagine what a gap would be made in the science if the Geometrical Optical work of Thomas Young, Sir W. Rowan Hamilton, and others named above, and more of comparable merit, still happily in active production, were excluded.

On the other hand, there is the old Munich school of Fraunhofer and Steinheil, with their theorist in aberrations, von Seidel, of supreme rank, though now a thing of the past. But the great modern object-lesson is the scientific organisation and commercial success of the firm at Jena under the direction of Zeiss and Abbe, apparently mainly in the smaller optical appliances which are commercial articles. It has been due, as is well known, largely to their enterprise in making experimentally all kinds of glass that had a chance of proving useful, and tabulating their optical qualities. But the very same problem was attacked in this country more than half a century ago by a solitary scientific worker—the Rev. W. Vernon Harcourt—and pursued for many years into practical results with the unrivalled advisory collaboration of Sir George Stokes; and it is understood to be generally admitted that, with the aid of even a very small subsidy from public sources, their neglected labours would have solved the problem that, in other hands, has carried so much *éclat*. Nor should the public-spirited work of British glass-makers be forgotten in our new-born and most praiseworthy zeal; the improvements effected at Chance's works at Birmingham under the direction of John Hopkinson are classical, and the inspiring energy of Sir David Gill promised just before his death fruitful developments in the astronomical direction, both there and at Blackfriars.

JOSEPH LARMOR.

Cambridge, 17th February.

"BRITISH OPTICAL SCIENCE." (NATURE, 5th April, 1917.)

As a manufacturer, may I be allowed to reply to Sir Joseph Larmor's letter in *Nature*, of 1st March, on the subject of British optical science, in which he makes certain statements that must create an entirely wrong and unfortunate impression of the circumstances?

What is the reason for the comparative smallness of the British optical industry? If one considers the pre-war output of the important German firms, it will be seen that they are based upon their military departments, of which the public of other countries knows very little. It only knows the German firms by their civilian productions. The German War Office in peace-time issued large orders for optical instruments, and placed them with German firms, on the principle that the optical industry would be a vital one in the time of war. Having such large orders to deal with, and having the certainty of continuity of work, the German firms were enabled to develop special machinery and appliances and to develop their general organisation.

As suppliers of the largest Continental Army, the German firms naturally obtained the bulk of the orders of other armies, with a consequent increase of their facilities and experience. In such circumstances it was comparatively easy to establish and maintain a civilian world trade.

Consider now the British conditions. The pre-war British orders were of negligible importance compared with the Continental ones. Where single orders for thousands were received by Continental firms from all sources, British firms received orders for tens. Anyone who is familiar with industry knows how difficult it is to compete with large firms under such conditions.

During the war, however, the British optical firms have received large and continuous orders, and, as a result, the increase of output has been very great. To have rushed a small industry in war-time and in so short a period up to its present size is a marvellous performance, probably unsurpassed in any other industry demanding exceptional skill.

But the important points to observe are that, so far as their knowledge was concerned, the principal British firms were competent to undertake the work, and that, having the orders, they were able to erect new premises, instal plant, provide special jigs and tools, train unskilled labour, find suitable materials, and, in these extraordinary circumstances, to produce instruments that satisfy the requirements of the Services. If in peace-time military orders of reasonable size had been placed in this country, the optical industry would have dealt with them as it has during the war. It is largely a question of orders of reasonable size, and, above all, continuity of orders. Having pilloried the optical manufacturer, Sir Joseph Larmor proceeds to praise the British optical writers. It is suggested that their works contain information that the manufacturers lack. In Germany and in Britain it is not the type of book cited by Sir Joseph Larmor that is used by the optical manufacturers. Not one of the books cited deals with the method of optical computation actually adopted in the German workshops, and, indeed, there are extremely few books in Germany that do divulge the whole system. The British books are, no doubt, well adapted to enable students to pass examinations on general optics. For example, one of the best of those cited has a large index, which includes the rainbow and the principle of relativity—questions, no doubt, that will find a place of honour in examination papers—but which does not refer to so vital a question as coma, to which alone a whole book should be devoted. There is a great similarity in the present optical books. They all contain the same stereotyped material. Some deal with it in a non-mathematical way, while others attack the propositions with heavy algebraic artillery. Generally the sign convention changes without warning from page to page, for the simple reason that the matter is mostly copied from previous writers who used no standard system.

No doubt these books are the unfortunate result of circumstances. A book devoted to, say, coma would have a very limited market, whereas a book on optics, if made sufficiently general, can be made to appeal to students and school teachers and thus find a profitable market.

In the early days of the optical industry in this country, our pure mathematicians were also real craftsmen. They were not content with the evolution of general equations. To-day " the science of the best optical instrument makers is far ahead of the science of the text-books." That is the opinion of the late Prof. Silvanus P. Thompson, who also said : " But the teaching of the colleges and the university teaching at Cambridge—well, what is it in optics ? They call it optics, but it is really purely mathematical gymnastics applied to the optical problems of a hundred years ago. I do not think there is really what one can truly call optical work going on at Cambridge. . . . . Optical teaching, I am sorry to say, is very largely at its lowest conceivable ebb."

If our present-day mathematicians wish to help the industry (and their help is desired), they must enter the workshops first as learners, not teachers. They may find the work laborious and monotonous from the point of view of the mathematician to whom a pretty solution is an object of some importance, but once they have experienced the pleasure of testing a system that accords with their calculations, they will never again be satisfied with the publication of untried formulæ.

James Weir French.

Anniesland, Glasgow, 28th March.

" Talbot's Observations on Fused Nitre." (NAT., 1st February, 1917.)

Lord Rayleigh recalls some observations of H. F. Talbot describing the appearance under a microscope (with crossed Nicols) of the solidification of fused potassium nitrate.

If a drop of a solution of nitrate be evaporated to dryness on a small plate of glass and the heating continued until the nitre is fused, it will spread itself in a thin transparent film over the surface of the glass.

" If the film is viewed under a microscope (with Nicols crossed), there appear crystalline plates of irregular shape, often fitted together like a tesselated pavement, each plate forming a single crystal. If one plate is darkened by rotation of the Nicols, the others remain visible in varying degrees of brightness. If the plates are thin, the light is white ; but with more salt they display colour, which is not always uniform over the plate, indicating varying thickness. After some minutes the plates break up in a surprising manner, and the general appearance is totally changed.

The transformation may be accelerated by touching the film of fused nitre (three or four minutes after forming) with the point of a needle. If the plate is viewed in a field of maximum darkness, the touch of the needle immediately produces a luminous spot on the dark surface which slowly expands itself in all directions like a luminous wave. If the film is touched prematurely within the first minute of solidification this change does not take place.

Lord Rayleigh found that protection from atmospheric moisture and storage at a temperature approaching 100° C. for five hours failed to prevent the transformation. If, however, the plate is kept over a small gas flame the plate behaves like one newly formed; he states that the potassium nitrate may be replaced by potassium chlorate, which shows less intense colours than the nitrate, but the plates with potassium chlorate may be kept for weeks in a warm room.

Other salts (*e.g.*, silver nitrate) which fuse in the anhydrous state without decomposition may also be employed.

A. W.

PERSONAL NOTES OF MEMBERS.

Mr. R. D. Linford, Student member of the Society, was gazetted on the 16th February, 1917, as 2nd Lieutenant, attached to the 3rd Battalion of the Royal Warwick Regiment, Parkhurst, Isle of Wight.

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